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AUTHOR Lloyd, R. Scott
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ABSTRACT

Holograms are capable of taking the two-dimensional ways of envisioning information to another dimension of presentation, representation, and conceptualization. Educational holography is joining display holography, holographic testing of materials, and holographic optical elements as a fourth major field in holography. Holograms are explored as educational tools to explain information visually to everyone. Holograms, based on a unique way of precisely recording light interactions as wavefront interference patterns, are not limited to recording images from original objects, but may be used to synthesize views of anything that can be represented graphically. Embossed holograms have been the most widely seen mass-produced holograms, as the "National Geographic" covers have demonstrated. Making holograms of this type and other varieties is reviewed. Holography can be put to the service of visual literacy, and can dramatically change the ways in which people communicate by graphic information. Educational holography will not solve all problems for visual literacy, but it can suggest where problems exist and point out connections to other disciplines. (Contains 6 references.) (SLD)

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An Introduction to Educational Holography

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by
R. Scott Lloyd

Holograms and the effects of holography are all around us in this country. They are most evident in three general applications fields of holography that have emerged since the mid-1960's, when lasers became available to be used as a light source for making holograms. These fields are: display holography (popular commercial and fine art images), holographic non-destructive testing of materials (technology of holometry), holographic optical elements (Museum of Holography, 1983).

Holograms are capable of taking the current two-dimensional ways of envisioning information to another dimension of presentation, representation, and conceptualization. It is in this context that educational holography is now emerging as a distinct, fourth major application; one that is no longer seen as exclusive to the training of holographers, but one that can benefit learning in all disciplines.

Two broad arenas of significance for this fourth field are:

1. expanding the diverse educational roles of holograms, themselves, as a tool for showing visual information in ways that print and electronic media can never comparably approach (precise size replication of objects in length, width, depth with parallax, and options for demonstrating motion);

2. and exploring holography conceptually, as a way to restructure the assumptions of critical, basic elements of visual literacy to become consistent within and between the disciplines of the arts and sciences.

The purpose here is to present holograms and holography in the service of general education and visual education. Holograms will be explored as educational tools to be used more widely for visually explaining information to everyone. Positive ways to make use of the mass-marketed, commercial and popular holograms, in the service of several educational purposes, are also suggested. As holograms and their educational uses are discussed, unique characteristics of the medium will also be highlighted.

The practical use of holograms, and the enhancements of concepts about the visual nature of actual objects and images, will often be presented together here. This is because the curious visual phenomena displayed by holograms will often spur the reader to want to know, immediately, why or how that characteristic comes to be. If someone tells you that she has just turned an object inside out, it is reasonable to suspect that you will want to know more about this with little delay. It is also done this way to encourage more conscious thought about what is seen, when looking at something.

Since the act of seeing among sighted people is so common and unconscious, very few people, even among those deeply involved in the visual arts, take the time to seriously investigate the assumptions by which their own visual literacy is structured. Those who have not begun to conceptually accommodate the visual characteristics of holography to their visual literacy structure, operate by

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and perpetuate visual misconceptions and frailties embedded in culturally-based, 2-D dogma.

See for yourself. Closely investigating the hologram on your credit card can be a good place to begin. Looking at holograms contrasts greatly with looking at 2-D images, and even other forms of 3-D optical imaging. Serious investigations, of what holograms do and why, will inevitably lead to the exposure of assumptions about what each of us thinks he or she sees, and, as a result, will accent many conflicts between them and what holograms demonstrate.

When the author's more serious visual investigation of holograms began, the novelty of holograms was replaced by a desire to do more than casually reconcile or ignore these mysterious conflicts. Holography has prompted a more engaging effort toward identifying a consistent set of fundamental, cross-disciplinary, visual phenomena to be considered in the restructuring of basic visual literacy.

Introduction

Holography is based upon a unique way of precisely recording light interactions as wavefront interference patterns (Gabor, 1972). In holography, the interference pattern captured in light-sensitive recording film is called a hologram. In order to record the fringes of light, necessary for a holographic interference pattern, a coherent light source such as a Helium Neon (HeNe) laser is imperative.

A hologram is made from the coherent light directed onto the holographic recording film (reference light), combining correctly with the light reflecting from or through the object being recorded (object light), in the light-sensitive recording material. Individual units of light (best described here as wavefronts of light) from the object and from the reference light meet, and in varying degrees, interact positively or negatively. Where they meet more negatively, little or no light is recorded, and where they meet more positively, light is recorded in the holographic film. This recording becomes a series of microscopic fringes of positive and negative interference on a fraction-of-a-wavelength level. The recorded fringes of wavefront interaction, resulting as an overall holographic interference pattern, contain wavefront information about the amplitude, wavelength and phase of object light, compared with the reference wavefronts.

The nature of this pattern requires that, in order to view the object information, an appropriate light source be directed at the hologram in the same place as the reference light was when it was created. (Otherwise the hologram looks like nothing, or nothing recognizable.) Under this correct illumination, the fringes in the interference pattern will select out certain wavelengths, to reconstruct the wavefronts of the object, to appear at the same locations in space from the holographic recording material, as they were during the recording.

Holograms record and reconstruct the phase information of an object's light, in addition to wavelength and amplitude information, in direct relation to the wavefronts of the reference light that illuminate them. A non-holographic, photographic, process can only record a pattern of brightness from the object, even if a HeNe laser and holographic film were used, because the phase information will not be recorded in an immediately accessible way.

It should be mentioned early that there are many ways to optically record, create, and display the illusion of a three-dimensional reality -- from many simple stereographic techniques used in photography and printing, to the latest advancements in virtual reality machines. Each has not strengths and weaknesses, but more and less appropriate applications to be determined by the context in which they might be used. Among these 3-D media, holography is the first and only one that can faithfully record and later reconstruct objects with the object's exact, functioning, optical properties as wavefront information.

The holographic process is not limited to recording only images from the original objects. Holography can be used to synthetically represent actual objects from a specially animated series of 2-D images which may exist among things we see, cannot see, or will never see (such as

mathematical formulas), into the three spatial dimensions, with motion or time. Parallax can be constructed by "holoptically" combining logically animated sequences of 2-D views. The holographic aspect seen involves the reconstruction of the series of flat views, so that they optically blend together in space and appear as a solid entity. Anything that is able to be represented graphically, in appropriately animated sequences, can be synthesized to exist three-dimensionally as a form of holographic stereogram.

Educational applications of mass-produced holograms

Embossed holograms are probably the most widely seen mass-produced holograms. They are the ones produced with rainbow-colored images on silvery backgrounds, often found on printed matter or on plastics as stickers. Perhaps the first embossed holograms to become widely known were the three published on covers of *National Geographic*. The first hologram of a crude model of an eagle was embossed onto the cover of the March, 1984 issue. It was the largest run embossed on a magazine to date -- several million -- proving holography to be an extremely viable mass-communication medium in the print world. It was quickly followed by the Taung skull (which was more than twice the size of the first), also embossed onto several million covers for the November, 1985 issue.

Each issue marked a significant advancement in the size and creative imaging capabilities of embossed holography in printed media. This magazine's last holographic accomplishment, for the December, 1988 issue, was a totally embossed front cover, back cover, and spine -- not a molecule of printing ink.

The embossed form of holograms can be:

- of objects holographed directly, as the model of the eagle or the Taung skull,
- as a holographic stereogram from animated flat images,
- as a flat graphic such as the credit card graphics,
- or as a "non-objective" holographic optical element such as diffraction grating.

There are dozens of very inexpensive holograms available as demonstration resources, ranging from past magazine covers, toys, and cereal boxes, to popular holographic images sold in the shopping malls across the country. These display applications are most often seen as commercial art, but also have a strong application as a fine art medium. The popular and commercial image markets have helped bring more holography into the hands of more people than fine art holograms. There are benefits and there are drawbacks to this.

Often commercial clients for holograms have cut corners on aesthetic quality, for quantity of sales. The same problem has occurred throughout the history of all stereographic processes too. This has led many lazy viewers, artists and critics included, to somehow think that these images were the only ones being created, and somehow represented the zenith of artistic exploration in the holography medium, and in 3-D imaging in general.

Ask a crowd collected for a talk on holography, what names they associate with holograms. The names will not be those of veteran artist holographers who have shown in dozens of museums and galleries all over the world such as Benyon, Deem, Berkhout, Moree, Crenshaw, or Wesly, but *National Geographic*, 'those trading cards,' 'that cereal,' 'the credit cards with the bird,' and so on. People often have seen holograms, but rarely ones that challenge the potentials of the medium. It is like judging the images in print by the ones found in junk mail. The commerciality of holograms has been a mixed blessing in educating people about holography.

Rather than turning up a nose at some of these images, it would be better to put these holograms to work positively in education. Exposing students to three-dimensional imaging for more than the image content could stimulate early interest in science, as well as show room for improvement in the art and design sides.

For example, simple investigation of common holograms, that may be far from an art museum's aesthetic, can still yield other exciting results. By holding

one of the silver-backed holograms upside-down, the image will "turn itself inside-out" and reverse its depth. The questions that result from this first level of exploration are immediately very challenging to our common perceptions about how images from a flat surface should behave. How does this holographic image do this? What seems to be happening? Why does the image exist as it does normally?

Children are curious to know how and why things work. The teacher will have to investigate 3-D imaging, some basics concerning optics, and may be moved to check up on some of the fascinating history of this Nobel Prize-winning medium. Children may listen to a statement like "Scientists are explorers also," but when they can explore science, the proposed idea meets the reality of the task they are performing with holograms.

Holography was a mistake that was discovered in pursuit of solving another problem involving electron microscopes (Gabor, 1972). The idea for holography was explored through the ideas of many scientists. Holograms, in an historical context, can be used to trace that history of ideas and learn about optical principles demonstrated by holograms. Here is where the teacher can also be very inventive, even though the most common, popular holograms are being used for demonstration.

Suggestions for developmental levels, for educational applications of holograms in the classroom, are not yet in place, because educational holography is such a new idea. The information surrounding holograms does exist in developmentally staged approaches for teaching -- the study of light, simple optics and so on -- and can be introduced appropriately from this experience.

Another example of an educational use for existing holograms involves children, young and old, with hands-on investigations of the different results obtained from different lighting and light sources for holograms. Students can see for themselves which light bulbs work better or worse, and set up simple scientific investigations. Observations and comparisons from looking at holograms and ink-printed text through different colored transparent gels can involve the students in exercising new visual experiences and connections. This kind of basic investigation and problem solving, involving the visual world, also brings up students' common levels of visual literacy, and bridges between the visual basics of the arts with the sciences.

There are relationships between the color of light and the color of objects that should not be exclusive to any one discipline of study. Working with holograms invites interdisciplinary introductions to light in a way that involves students. Edwin Land did an extensive series of experiments about the perception of color reflected from different pigment colors that were illuminated under different wavelengths (colors) of light (Land, December, 1977 & 1990). Older students of physics, psychology, and art alike, would benefit by experiments using common holograms and different colors of light for clarifying that pigments are materials, not colors. Holograms will never be understood without discovering these kinds of basic concepts.

These concepts then can be used to challenge other common assumptions about the visual world. In art classes, the traditional color wheel is based on pigment colors whose primary colors are red, yellow and blue. In science class, the primary colors of light are red green and blue. At an early age the distinction could be demonstrated and at a later age explained more in depth along with examples of subtractive and additive color.

Explanations of three-dimensionality can be aided by the use of common commercial holograms too. While it is important to learn the western, 2-D languages and symbol systems for picturing depth and dimensionality, it is also important to know about the physics, psychology and physiology of light and dimensional perception. Holography provides an excellent springboard into investigating this subject.

This is not only an issue for the sciences mentioned, but also one that is cultural and artistic. Students can evolve their study of how they see "mechanically," to how they and people from other places visually perceive pictorial languages -- people give images meaning. A

curious aspect of this cultural interpretation is exemplified beautifully by showing people of all ages and backgrounds different holograms of people (recorded with a very powerful pulse laser). It appears that many people, especially adults, would not like to have a holographic portrait of a loved one displayed at home -- the response, more often than not, has been that such a hologram is "too real" and ultimately "too creepy".

Now that the general public is used to photographs, movies and television images of people, why have so many adults interpreted holographic portraits as "too real"? This dimension of holography was very surprising. Could this uneasiness be changed by reducing the portrait size and scale? Is color a major factor? Would achromatic portraits be more quickly and easily accepted? Are Americans the only ones who feel this way?

Popular holograms whose images reconstruct animals and sometimes optically interesting phenomena may not have the aesthetic depth of those produced by serious, practicing art holographers, but can be used as a focal point for introducing topics in creative writing, poetry, and literature. Once again, young children enjoy playing with light and looking at plants and animals. There are dozens of holograms, whose images are of animals such as birds, puppies, snakes, spiders, kittens, clowns, and even children. Small, pleasant-looking images of children and animals have not seemed to be upsetting to children from my observations -- the response is actually the opposite. These kinds of images range in size from 3" x 3" to 12" x 16". Prices range from $5 to $75, usually according to size.

A story about an animal can begin with the hologram to attract attention, and focus the story topic. The students can write about the dog in the hologram, and why this one might be so special. Poetry topics can be involved in similar ways. It is another opportunity for education to become more creative for the student and the teacher, and for science to enter the arts in a positive way.

Holographic diffraction grating can be purchased for a few dollars per square yard. It can be used to illustrate science lessons about light diffraction. It is inexpensive enough to be cut up and distributed among the students as a material to use in making art. Younger children often prefer diffraction grating to holograms of recognizable images probably because the diffraction grating is far more colorful, visually kinetic, and can be transformed into designs under the child's control. Projects for elementary children with this material have included making jewelry, buttons, postcards, abstract and realistic collages with other colored materials, logo designs, typography, and more. This introduces the colors of light with the colors of pigments. It also helps convey the idea that color is light, not something material. The flashiness of the spectral diffractions from this material also brings a bit of excitement from science to art. Optical manipulation of light normally done only with prisms or oil-slicks is expanded to new experiences.

The contexts of using the holographic diffraction grating material could also be played with -- to what other functions could this material or variations of this material be applied? Holograms need to be experimented with visually and conceptually in different materials contexts, so that the other materials as well, become better known from their contexts with holography. A stripe, rectangle, or sharp triangle in construction paper placed with similar shapes of holographic diffraction foil, provides contrast in shape relationships on a page. It also adds new understandings of depth relationships where the holographic material extends colored light into or above the surface of the paper.

Making Holograms

When holography was invented in 1947 by Dennis Gabor, the laser did not exist. In 1948, the most coherent light source he could find for the first experiments in making holograms was a high pressure Mercury lamp (Gabor, 1972). The coherent light of a Helium Neon (HeNe) gas laser is now most often used to make holograms in the holography lab of artists and schools. This laser light is desirable for making holograms for several reasons:

- it emits pure monochromatic light (only one wavelength/one

color);
- the light is coherent -- essentially promoting the ability of the phase information of light to be recorded intact as object/reference interferences fringes;
- and the light travels in a straight line making it highly directable.

Because of federal standards of laser safety regulations, HeNe lasers of under one miliwatt of output should be used in a demonstration context for schools, unless there is a teacher on premises who is a certified laser safety operator. The low-watt HeNe lasers used in holography do not burn. The greatest danger from the HeNe laser (or any light source) exists in looking directly at its concentrated beam of light. These one-miliwatt lasers easily expose film sizes at, or under, 3" x 3", which is an excellent demonstration size for schools. The holograms made, should always be ones viewable by white light to avoid problems with laser-viewing, and, because an appropriate clear, single-filament, incandescent light bulb, will cost about 69 cents. Exposing holograms in sizes larger than this requires that the laser light is spread out more to cover more area. This will weaken the intensity of light and require longer exposures under extreme anti-vibration conditions.

The film typically used with the HeNe laser is a glass-based or triacetate film, coated with the light-sensitive emulsion of hyper-fine Silver-Halide suspended in gelatin. The cost of a one-miliwatt, used laser can be under $100., and a box of 100, 4" x 5" sheets of triacetate base film should also be under $100. Some developers can be found in better photography stores, or made from scratch from chemicals on hand in the school chemistry lab, or ordered in bulk by mail. With a bit of thinking and successful conversation, portable educational labs for schools can cost under $1000. Holographers will always offer advice and must be consulted in the start-up stages to better guarantee early success. Even the best written materials cannot assess expectations or the conditions under which a holography setup is expected to function.

Several schools are taking advantage of learning from existing, mass produced holograms and are making their own holograms in the classroom. This is where the discovery in the arts and sciences can truly soar. At the end of manipulating ideas initially based in physics, chemistry and art, there will exist a hologram as evidence that can be shared and investigated further by students, teachers, parents and the community.

Between 1984 and 1989, I built the first collaboration between the original Museum of Holography (M.o.H.) and twenty school districts across New York State called The Holography in the Classroom Project (H.I.C.P.) (Lloyd, Spring, 1986). This project involved thousands of high school students, and over a hundred elementary students, in holography. We built nine permanent or temporary holography labs in high schools, and one portable lab in an elementary school. The students were sponsored by at least one teacher, personally trained by the author, through the M.o.H., Educational Services Department. This information was then passed on to the students and whenever possible, to other teachers in other disci plines in the district, and shared at conferences in the arts and sciences.

At a time when non-profit and educational funding was plunging, and grants were extremely competitive, holography enjoyed very reasonable support. Through the Museum, the author wrote H.I.C.P. grants for over $35,000 from the Arts in Education Program of the New York State Council for the Arts, in collaboration with interested schools and the N.Y. State Education Department. Teachers from all over the state of New York were invited to become involved. The participating teachers were from formal disciplines in either English, Physics, art, general science, computers, or marketing.

The focus of the H.I.C.P. was to create a collaboration between the teachers and the director of the Educational Services Department at the Museum, where holography would be developed as a curriculum enhancement tool. Many exhibitions of student work, community publicity, and a unique project that led high school students to design and mass-produce their own world-first hologram on the cover of their yearbook, were some of the more obvious achievements.

Less obvious are the behind-the-scenes processes necessary to create a successful hologram. These can be small administrative coups, as in the H.I.C.P. high school that convinced the male faculty to relinquish a restroom for a holography lab. Another was the convincing of community businesses to donate materials for a vibration isolation table and glass for the film holder.

There is something very magical in the process that is at least equal to the practical, physical considerations. The working conditions involved with holography are more extreme than in photography. Unlike photography, the anti-vibration factor in making holograms is critical. It makes the holographers hyper aware of the sources of the slightest sounds or vibrations. During the dark time in shooting holograms, the room must be kept nearly totally dark -- even though the film is slow, it is being manufactured at more panchromatic sensitivities.

When making holograms, often story telling occurs during the "dark time". Working with the intense red "cream-of wheat" texture of laser light always reminds holographers that they are doing something different, something special. The intense precautions against vibrations that often humans cannot perceive seem superstitious. Processing no "picture", and not being able to confirm successful results until the hologram is dry and receives the correct light and angle of illumination, can become a kind of ceremony. These are some things that all holographers share.

In display holography, especially, the variety and diversity of backgrounds and cultures of people involved is astounding. While there can be drawbacks to making holograms such as the anti-vibration factor, the youth of the medium can also yield a vital community, filled with sense of sharing a very special activity. An artist will show some compound lens distortion techniques recorded purposely to create a wild bouquet of colored light to a scientist who sees beauty in something he was trained never to do with holography. The scientist shows the artist a hologram of a wavefront of one pulse of light travelling over the surface of an object. Imagine, a hologram of just a piece of light; the artist finds beauty in scientific observations as well.

A holographic image may display curious tiger, wood-grain, or concentric stripe patterns. These were not created by a change in color on the object but a change in the light coming from the surface of the object. During an exposure with a low-power laser, if the object moves more than a quarter of a light wave, the object, or the part of the object that moved will not constructively record its interference pattern correctly. Double exposures of objects, with a slight variation in the object's surface from pressure or temperature introduced between the exposures, will record the same object twice in the same place noting the degrees of differences by striped patterns. The dark stripes are where the light destructively interacted; the light stripes indicate where it was positive.

Artists control this for a visual effect, while scientists use this to gather important information about changes in materials and products. This way of recording represents one of many forms of holometry -- holographic non-destructive testing. It is a scientific application to determine points of surface change in objects and volume change in gas and liquid. Formally and conceptually, artists can explore change as art or just use the stripes as a decorative element.

Holographic optical elements (H.O.E.'s) use the optical properties of holograms to create holograms whose purpose is not to reconstruct objects but the optical manipulation properties of refraction, reflection, and diffraction. Complex, lightweight optics have made possible diffraction grating discs used in laser scanners, such as the ones in supermarkets, that could not have been created without holography. Head-up displays in car windshields and pilot helmets can optically locate light information into space at precise distances.

This type of hologram is also employed in solar collection as a way to always catch the most intense direction of sunlight and refocus it to solar stationary collectors. A twist on this last idea is being considered for holographic windows to direct more sunlight to poorly lit rooms

in tall city buildings. How might students want to creatively manipulate light holographically in ways not yet imagined?

Artists have used H.O.E.'s to create art that is totally non-objective. At this level the artists are truly sculptors of light itself. Brilliant bursts of rainbows can be orchestrated by the artist to appear and disappear in space as the viewer walks by, or moves up and down. Light can be made to appear at only one location out in space where the mind is not used to looking for information. Some viewers can miss information that artists present because their minds have been trained to focus only at the surface of artworks -- imagery is not supposed to just appear without a location to a surface in space under the rules of drawing and painting.

Non-destructive testing and holographic optical elements can also be made in the school lab with the one-miliwatt laser. As students and teachers spend time investigating holography, it becomes evident that holography truly is something special, something magic. The questions it poses and the elegance of some of the solutions it demonstrates regarding aspects of visual realities, perceptions and myths have to be presented very poorly in order to become uninteresting.

For example, one of the latest frontiers related to, but not entirely consistent with holography, is phase conjugation (Leith, 1986). It is a new application, also called "transholography" (Denisyuk & Gurikov, 1992), that addresses elusive, complex issues involving time-reversal. Exploring this area cannot happen in the school lab currently, but the school lab can spawn discussion that can be assisted by basic knowledge in holography.

Holography in the service of visual literacy

The ways in which people communicate by graphic information will dramatically change after experiences of making holograms, if people pay close attention to what holograms are demonstrating. This does not mean that people will be suddenly or exclusively thinking "holographically" (what ever that means), stop drawing pictures, or insisting on taking up residence in a holography lab. What it means is that a new, clearer awareness of light at the core of organizing information involving visual literacy will emerge. Making holograms and seriously exploring what holograms do, can help to challenge the inconsistent, patchwork of current assumptions. When a hologram of a baseball gets the top left corner cut off and the whole baseball can be seen through the much smaller hologram piece, it should not just instigate questions about how a hologram does this but add to information about how light itself functions.

The "age of information" is hopping a ride on the "age of light" for the next century. Theoretically, it has been suggested that the contents of the Library of Congress could be recorded holographically into in a volume that will fit on a spoon. This is difficult to write, let alone imagine. Schools have to prepare the next generations for these levels of challenge. The information cannot all be shared exclusively by reading words. Visualization of information will increase in educational importance, and 2-D images are not able to accept the entire burden.

When explaining holograms briefly in this paper, it would have been lovely to have the hologram not yet made, that showed light moving from the laser, to the film and object, and on to create the interference pattern in the film -- three-dimensionally, with parallax, and with movement. 2-D graphics that become part of the language and symbols of holographers, can be immediately understood by holographers, who are already fluent in the basics. 2-D graphics rarely have helped holography novices make immediate transitions from words about the medium, to the flat diagram, to an accurate mental picture, especially in an article of this size.

Fluency in the concepts and functions associated with holography are also rarely present or consistent among novices as well. This suggests that learning more about holograms also means that disciplines within the arts and sciences will have to open their doors to sharing information; that collaborations in investigating new assumptions about the structures of visual literacy can no longer exist in exclusive domains of academic disciplines.

Educational holography will not solve all of the problems for visual literacy. It will show where problems exist, and suggest points of connection between it and other disciplines, from which to begin. Its newness is exciting, and when introduced in a non-intimidating fashion, extremely inviting. As holograms begin to take the mystery out of visual phenomena, the magic will surely remain.

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